SNS-103000000-DC0001-R01

DESIGN CRITERIA DOCUMENT

WBS 1.3

Front End Systems

Date: February 2003

SPALLATION NEUTRON SOURCE

A U.S. Department of Energy Multilaboratory Project

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

SNS

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SNS FRONT END SYSTEMS

1 FRONT END SYSTEMS OVERVIEW

The primary function of the Spallation Neutron Source Front-End Systems (FES) is to produce an appropriate beam of H^- ions and inject it at 2.5 MeV into a following linear accelerator (linac) chain for further acceleration. Figure 1-1 shows the principal front-end beamline components and their Project Work Breakdown Structure organization and relationships:

- H^- ion source (IS)
- Low energy beam transport system (LEBT)
- Radio-frequency quadrupole linac (RFQ)
- Medium energy beam transport line (MEBT)

The ion source is a multicusp, rf-driven, cesium-enhanced plasma generator with extraction and electron-dumping systems, designed and engineered to provide high peak H^- beam current at 65keV extraction voltage with the required emittance at the required duty factor. The LEBT is a compact, two-lens, all-electrostatic transport system. It is required to provide transverse matching of the beam into the acceptance of the RFQ, pre-chopping at 65keV energy, and beam steering.

The RFQ structure itself incorporates design concepts developed in earlier LBNL RFQs, but is required to operate at 6% duty factor or more. The RFQ bunches the beam and provides acceleration from 65 keV to 2.5 MeV energy.

The MEBT is required to transport the beam from the RFQ to the drift-tube linac (DTL) and provide proper beam matching in both transverse and longitudinal phase space. The MEBT incorporates a fast chopper and anti-chopper system that are developed and built by LANL.

Supporting technical components are to satisfy the associated instrumentation and control requirements. Also required are local water systems (for cooling and temperature stabilization), vacuum subsystems, and support and alignment capabilities.

The requirements for the front end are established by the 1.4-MW overall specification for average ion-beam power of the Spallation Neutron Source and by the associated requirements of the other major accelerator systems. Operation must be extremely reliable and commensurate with routine usage as part of a major user facility. The Front-End Systems are developed and produced as an integrated package and fully beam-tested at LBNL prior to delivery and installation at the SNS site.

Table 1-1. Key Front End System performance requirements for SNS operation at 2 MW.

Parameter	1.4-MW facility
Ion species	H^-
Energy (MeV)	2.5
H^- peak current at MEBT exit (mA):	38
RFQ frequency (MHz)	402.5
Beam duty factor (%)	6.0
Repetition rate (Hz)	60

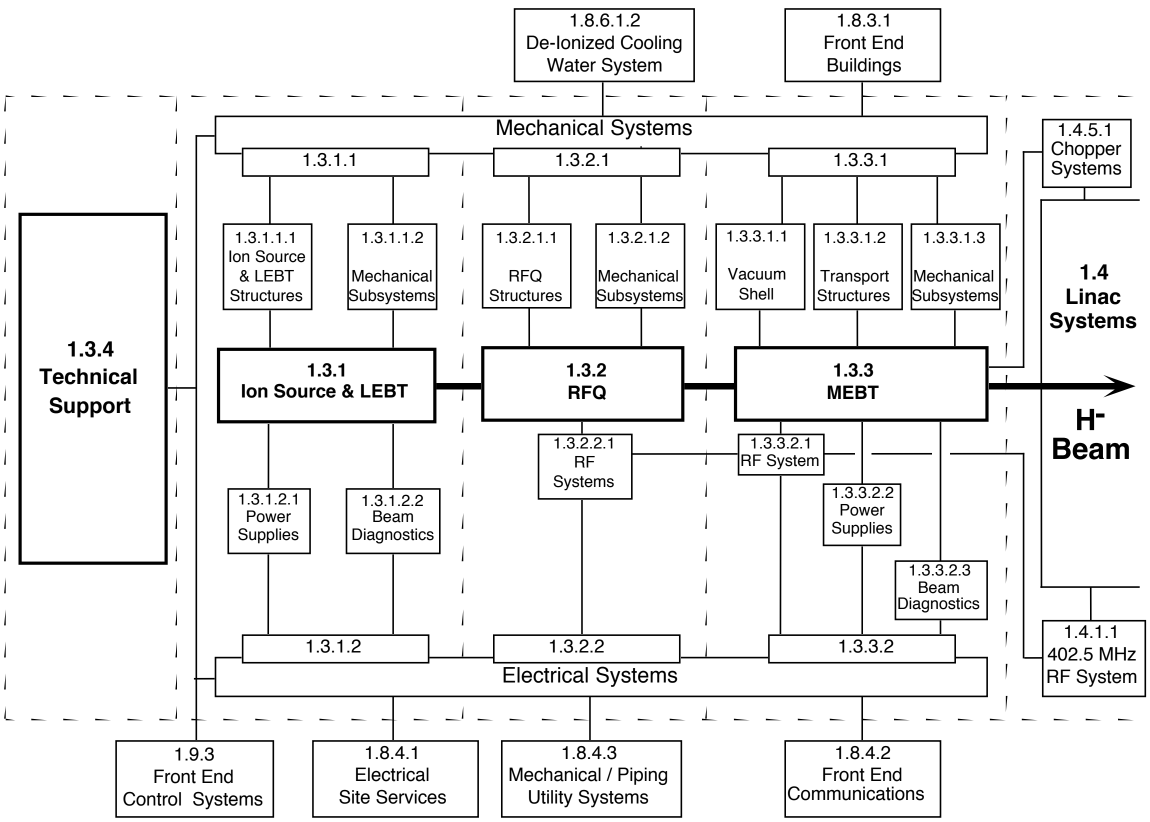

Fig. 1-1. Schematic layout of Front-End Systems showing component interrelationships and associated WBS numbers.

2 SUBSYSTEM REQUIREMENTS

2.1 FRONT END DIAGNOSTICS AND INSTRUMENTATION

The diagnostics elements required for the Front End Systems measure the most important beam parameters, allowing the overall tunes of the front-end beam to be set, and then continuously monitor proper accelerator operation using non-intercepting monitors. Intercepting monitors will be required for use during tune-up and measurement of longitudinal bunch characteristics. No magnetic spectrometers will be required, but wide-bandwidth phase-monitors will be used to observe the evolution of the bunch shape along the structure and provide beam-energy information. More details of requirements for specific diagnostic elements are given in the System Requirements Document for the SNS Front-End Systems, SNS 103000000 SR 0001.

2.2 WATER SUBSYSTEMS

For the front end systems a variety of water systems with different characteristics and supply temperatures are required. The IS/LEBT will require a relatively small flow of deionized (DI) water from the SNS facility. Additional loads for the RFQ and MEBT are also specified in the Systems Requirements Document. A flow rate of approximately

30 gpm for the Front End Systems and another 15 gpm for the “Hot Spare” test stand is required; a supply temperature of approximately 90°F is adequate.

Cooling water with a stabilized supply temperature of 75±1°F is required for the RFQ structure to maintain its tunable frequency range. Also, to minimize overall thermal deformation of the RFQ and frequency drift, the difference between the inlet and outlet water-temperatures has to be kept relatively small along the length of the structure. A second, variable, water temperature is used to adjust and maintain a desired temperature difference between the vanes and walls of the RFQ structure, thereby providing slow and precise frequency stabilization to the entire structure. This intermediate-temperature water will be supplied to the cooling channels imbedded in the vanes only, and it will be especially useful to compensate frequency shifts between the extreme operating conditions of shutdown and full operation. For the MEBT rebunchers, a stable temperature is required as well, and the same closed loop system that cools the walls of the RFQ will be used for MEBT rebuncher cavities. Two secondary water systems with closed-loop temperature-regulation will be provided to fulfill these requirements. The first one, operating at 75±1°F supply temperature with 110 gpm flow rate, will serve the RFQ structure and the MEBT rebunchers, and the second one, operating between 63 and 75°F with ±1°F precision and 25 gpm flow rate, will establish the desired vane temperature.

There will be one klystron installed together with power-conditioning equipment to serve the RFQ. Since the klystron is located in the klystron-gallery and will be of identical type of the DTL klystrons, an extension of the DTL-klystron water-system includes the RFQ klystron. The water requirements for this equipment will be expressed by LANL.

2.3 SUPPORT AND ALIGNMENT

The support and alignment subsystem consists of the structural support required to carry all front-end beamline-components, to allow them to be properly connected to the linac, and to ensure their compliance with the alignment requirements of the entire facility. This includes the mounting and interfacing of subsystems for vacuum, controls, water cooling, rf, dc- and ac-power terminations, and other commodities needed for the front end. All support systems must withstand seismic events specified in section 3.2.1, below.

The primary support structures are two steel platforms anchored to the building slab and carrying strut-alignment hardware. As a procedural approach, the natural frequency is designed as high as possible (maximum rigidity) to avoid perturbing the performance of the front end by any other machine or equipment excitation, such as a passing forklift.

Generally, the alignment requirements for front-end components are driven by considerations for overall beam quality and for beam-loss reduction. Beam degradation due to misalignment may occur if any of the beam-transport elements are transversely out of position with respect to the beam axis or rotationally misaligned (roll error). Longitudinal misalignments are generally less critical than transverse ones. The beam that leaves the RFQ should be within ±25 μm of the ideal MEBT axis, but this requirement can be fulfilled by beam steering, as long as the RFQ structure is aligned with respect to this axis within the ±100-μm transverse tolerance band.

The alignment of RFQ and MEBT will be based on measurements of the positions of external fiducials that have been indexed to features of individual components. These fiducials will be used to obtain position information in longitudinal and both transverse directions as well as rotation (roll) about the beam axis. The ion source will be keyed to the LEBT entrance-flange and does not require any additional external alignment. The LEBT electrodes are aligned against each other on a work bench and aligned with respect to the RFQ entrance aperture by using a dowel rod. Upon assembly, all front-end components are locally aligned with respect to each other, using finely adjustable supports, and the system as a whole will be aligned at installation in the SNS front-end building, making use of a subset of the component fiducials.

The concept of Survey and Alignment techniques and instrumentation is defined for the entire SNS facility in a separate document. It is expected that the accelerator components will be periodically resurveyed to detect possible misalignment (caused by floor settlement and similar effects) and routinely readjusted as needed.

2.4 VACUUM SUBSYSTEMS

The general vacuum goal for the FES is predicated on a pressure of approximately 5×10^{-7} Torr for most of its components, transitioning to approximately 1×10^{-7} Torr or less near the MEBT/DTL interface.

The overall design requirement is to provide adequate pumping and conductance throughout the system. A special design requirement is to pump the ion-source hydrogen gas-load that influences the beam loss at the first LEBT electrodes.

Parameters for sizing each system component are determined by three requirements:

- The out-gassing rates of the vacuum surfaces of the components
- Considerations of conductance, packaging, or general layout
- The need for high reliability and serviceability.

Based on experience with similar systems, the pump-down requirements are set to be 8 hours to reach the baseline pressure after pre-operational conditioning. As with most vacuum systems, the pump-down time will improve with longer operation. Vacuum-exposed components consist of copper, stainless steel, aluminum, and insulating ceramics with a minimum amount of tin gaskets, elastomers such as viton or silicon-based materials, and some cast epoxy parts.

The vacuum system for the front-end components consists of several two-stage vacuum-modules acting in parallel. The first stage is a roughing system in which the combination of a turbomolecular drag-pump and/or dry-diaphragm backing-pump will bring the beamline pressure down from atmospheric to approximately 10^{-5} Torr. The turbomolecular drag-pump has a high compression ratio for hydrogen gas and is free of backstreaming hydrocarbon because of oil-free bearings. The second, high-vacuum stage consists of cryogenic pumping for the RFQ and distributed ion pumping for the MEBT to arrive at the final beamline pressure of approximately 10^{-7} Torr.

Conceptual designs for the front end incorporate vacuum-pumping ports that are well distributed among the beamline components. High-vacuum isolation gate-valves are placed at selected locations throughout the beamline, to facilitate system maintenance. The cryogenic pumps are capable of partial second-stage regeneration through the integrated microprocessor controller. The pump-isolation gate-valve operation is interlocked with the pump controller.

Other features will include provisions for dry-nitrogen gas-purge if the front end is routinely going to be vented to atmosphere. This allows the preconditioning state in the beamline to be maintained to a high degree and reduces the pump-down time on subsequent restarts. Beamline isolation-valves for high-maintenance components will be incorporated to ease maintenance and operation. LANL will provide the primary isolation valve at the MEBT-DTL interface.

2.5 ELECTRICAL POWER

The electrical power requirements for the Front-End Systems (including a second operating ion source on a test and maintenance stand) are compiled in the Systems Requirements Document, SNS 103000000 SR 0001.

2.6 RELIABILITY, AVAILABILITY AND MAINTAINABILITY

The Front End Systems will be required to support the high level of reliability, availability, and maintainability envisioned by the SNS facility operation.

The ion source is expected to be the front-end subsystem with the shortest mean-time-between-failures (MTBF) and will be the element most subject to unpredictable failures. Thus, many of the efforts to meet the reliability goals have been focused in this area as part of the extensive R&D and integrated testing program. The ion source has been engineered for maximum lifetime and reliability with an envisaged average life of approximately three weeks. In addition, the ion source is designed so that all components requiring routine changeout are conveniently located on the back plate, permitting a source change to be completed rapidly and full beam current to be re-established in several hours.

In the design of the RFQ, particular care has been applied to the selection of materials and to the thermal stabilization of the structure so that thermal cycling and thermal stresses do not shorten the serviceable life of the cavity structure. Features such as rf joints have also been carefully engineered to ensure long MTBF. The specifications for the rf power-systems provide an adequate reserve so they will not be operated at their engineering design limits. A circulator is incorporated to prevent damage to the klystron that could result from excessive reflected power.

Wherever practical, common instrumentation, controls, and other components will be specified to ensure a common inventory of spares and facilitate efficient training of operations staff. The steps being taken and outlined here to address issues of reliability, availability, and maintenance are standard practice at successful user facilities now in operation.

3 DESIGN CRITERIA

3.1 OVERVIEW

Sound engineering principles and practices have been applied to the planning, design, and construction of all SNS facilities and equipment. The Front End Systems construction task was carried out by engineering and scientific staff at the Lawrence Berkeley National Laboratory (LBNL) with the goal of satisfying all applicable Executive Orders, federal, state and local laws, and regulations. DOE design management policy is implemented primarily through a series of orders and standards. In addition, several national codes and formal standards are applied to all LBNL work. These include the Code of Federal Regulations (CFR), OSHA, National Electric Code, Underwriters Laboratory (UL), ASME Pressure Vessel Code, etc. A series of applicable codes and standards used also include American Society for Testing and Materials (ASTM), Institute of Electrical and Electronics Engineers (IEEE), LLNL Engineering Standard References (ESR's), etc. Furthermore, the design of equipment at Berkeley Lab must incorporate all applicable codes and standards as required by LBNL's Health and Safety Manual (PUB-3000).

3.2 CRITERIA

3.2.1 Seismic Criteria

The Front End Systems and associated equipment must withstand a PC-0 earthquake, per DOE-STD-1020-94, at the minimum remaining stably anchored to the building slab without endangering personnel or other equipment, but not necessarily being fully functional after such an event.

3.2.2 Structural and Architectural

The Front End Systems and associated equipment is designed to accommodate structural settlement within the Front End Building, as well as differential settlement between the Front End building and the Linac tunnel and klystron gallery for overall settlement differences up to 2 inches.

3.2.3 Electrical Power and Grounding

Electrical systems are built to comply with the edition of the NFPA 70 identified as the code of record for the SNS. Electrical systems are designed so that all components operate within their capacities for initial and projected loads. Preferred standard voltages conform with ANSI C84.1 (ANSI, 1993a), with a single voltage level characteristic in any classification, to minimize stocks of spare equipment and to standardize operating and maintenance practices and procedures. All electrical equipment operating at or above 50V is contained inside enclosures that prevent accidental contact. Power distribution panels that shield conductors higher than 50V are bolted shut or protected by interlock switches.

A grounding system is provided for structural steel and equipment grounding in accordance with NFPA 70. All systems employing metallic tubing or piping (including associated conduits) that may act as a current carrying path to ground are effectively bonded together to keep the electrical potential differential essentially at zero. All electrical equipment, including panel boards, junction boxes, safety switches, etc., is securely grounded. All designs conform to the requirements of the Occupational Safety and Health Standards, 29 CFR 1910 and NEC Article 250.

3.2.4 Environmental Control

The RFQ operates at approximately 75°F. During operations the front end building temperature is to be maintained at 75° F ± 2°F with a maximum dew point of 55°F.

3.2.5 Materials and Processes

The FES components are manufactured and assembled in accordance with cleanliness requirements appropriate for high voltage and high vacuum equipment where appropriate.

3.2.6 Maintainability

The design addresses various maintainability goals such as mounting, modularization, standardization, accessibility, interchangeability, and handling. The design does not necessitate any scheduled maintenance on the RF structures, magnets, or diagnostic devices. Location of components mounted in or around the stand, support structure, and electronic equipment racks at the SNS site shall allow access for maintenance and removal.

3.2.7 Handling

Lifting eyes or fork lift points, or other safe means, are provided on all items whose weight and size require a lifting capability of 20 kg or more subject to removal during the operating life of the FES. Rigging and handling plans and procedures for all FES components have been examined with regard to safety and high value damage consequences.

3.2.8 Vibration

Performance of the FES will not degrade when exposed to the natural and local background levels of vibration expected at the SNS site. Vibratory motion will not have deleterious effects on beam quality.

3.2.9 Transportability

All items are transportable without detrimental degradation to performance. Provisions have been made for measuring and controlling shock and accelerations during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation were utilized to prevent damage. All containers and equipment are movable by forklift, crane, or other material handling equipment.

3.2.10 Instrumentation and Controls

Remote control and monitoring of vacuum gauges and ion pumps, temperature sensors, and temperature control unit use IEEE-488 computer interfaces. All instrumentation uses 120 VAC, 60 Hz. The control systems connects to the SNS control centers via networks accepted as standards for the SNS project. The FES controls interface with the facility-wide EPICS database system. Additional interface information is contained in separate documentation.

3.2.11 Assembly

The FES is designed for assembly and handling with tools and systems available in the SNS assembly facility. Inspection and test requirements utilize to the extent possible standard tools and equipment available at the SNS electronics, mechanics, and vacuum laboratories.

3.2.12 Testing

System test plans were developed during detail design to facilitate identification and implementation of vendor tests, construction acceptance tests and system tests that were performed to verify that the system components and installed systems satisfy functional requirements (e.g. pressure/proof testing, leak testing, weld examination, flow testing, high voltage, etc.). Integrated sub-system and system testing was carried out at Berkeley Lab prior to delivery to ORNL.

3.2.13 Layout

The layout of the FES systems was designed to facilitate equipment access and handling. Considerations that were addressed include:

Proximity of components near maintenance operations (e.g., “Hot Spare” test stand).
Physical limitations associated with the planned building construction sequencing and the corresponding schedule for installation of utility equipment and components.
Personnel access and mobility during maintenance.
Planned handling approach and accessibility for components.

4 QUALITY ASSURANCE

All activities associated with the FES were conducted in accordance with the requirements contained in SNS-QA-P01, SNS QA Plan; and accepted engineering standards and practices. Good engineering practices were incorporated into the established design process to ensure future safe and reliable operation of the SNS and mitigate conditions that could pose a threat to success. In all cases, consensus standards were used to accomplish design activities. Where existing standards did not adequately control an activity, appropriate administrative controls were considered. Successful QA program performance was verified through validation activities such as design reviews, surveillance activities, inspections, tests, and readiness reviews.

5 SAFETY

The FES was built to meet all applicable Department of Energy and other Federal safety regulations, plus those applicable State, Local, and SNS safety requirements, and the SNS Environment, Safety, and Health (ES&H) Plan. Equipment provided by LBNL must also meet applicable requirements of LBNL's Health and Safety Manual (PUB-3000). Particular emphasis was placed on restricting the use of hazardous materials where possible; grounding of electrical systems; interlocks and personnel and machine component protection, RF radiation emission; cleanliness. RF leakage shall conform to the requirements of ANSI C95.1-1982.

6 DOCUMENTATION

Technical documentation was delivered, sufficient in level of detail, type and quality to allow re-procurement or fabrication and satisfy the SNS documentation standards and practices. Electronic PDF files, or equivalent, were transferred to the SNS Document Control Center. The technical documentation package include the following categories:

6.1 SPECIFICATIONS

a. Fabrication Specification establishing the requirements for manufacture and acceptance of the FES equipment and components.
b. Process Specifications defining specific processes involved in manufacturing techniques.
c. Material specifications defining raw materials and semi-fabricated material (e.g. electrical cable, piping)
d. Interface Control Documents specifying the interfaces for beam input/output, vacuum, RF, water, and instrumentation.

6.2 ENGINEERING DRAWINGS

Drawings and associated lists were provided. SNS Drawing Numbering System, and Global Drafting Manual, supplemented by procedures and instructions pertinent to SNS specifically, were used as guides.

6.3 TECHNICAL PROCEDURES

Procedures were provided for:

a. Initial installation and set-up of equipment
b. Equipment conditioning
c. Normal operation of equipment
d. Normal and/or preventative maintenance

6.4 TECHNICAL MANUALS

Manuals were provided for all purchased components and subsystems delivered to SNS.

6.5 DOCUMENTATION NUMBERING

The SNS document numbering procedure was followed. Dual document numbering was applied to conform with both LBNL and SNS standards.